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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Upper limit dose estimates (internal and external) are determined for those units of the U.S. occupation forces assigned to Hiroshima or Nagasaki following the detonations of atomic weapons in those two cities. In the absence of specific maneuver and patrol data, these dose estimates are based on the maximum recorded activity levels with exposure over the entire stay period for each unit. The upper limit external dose is .03 rem for Hiroshima and .08 rem for Nagasaki. For the Nishiyama area, the upper limit is 0.63 rem. The dose from internal emitters (inhalation and ingestion) is considerably less.

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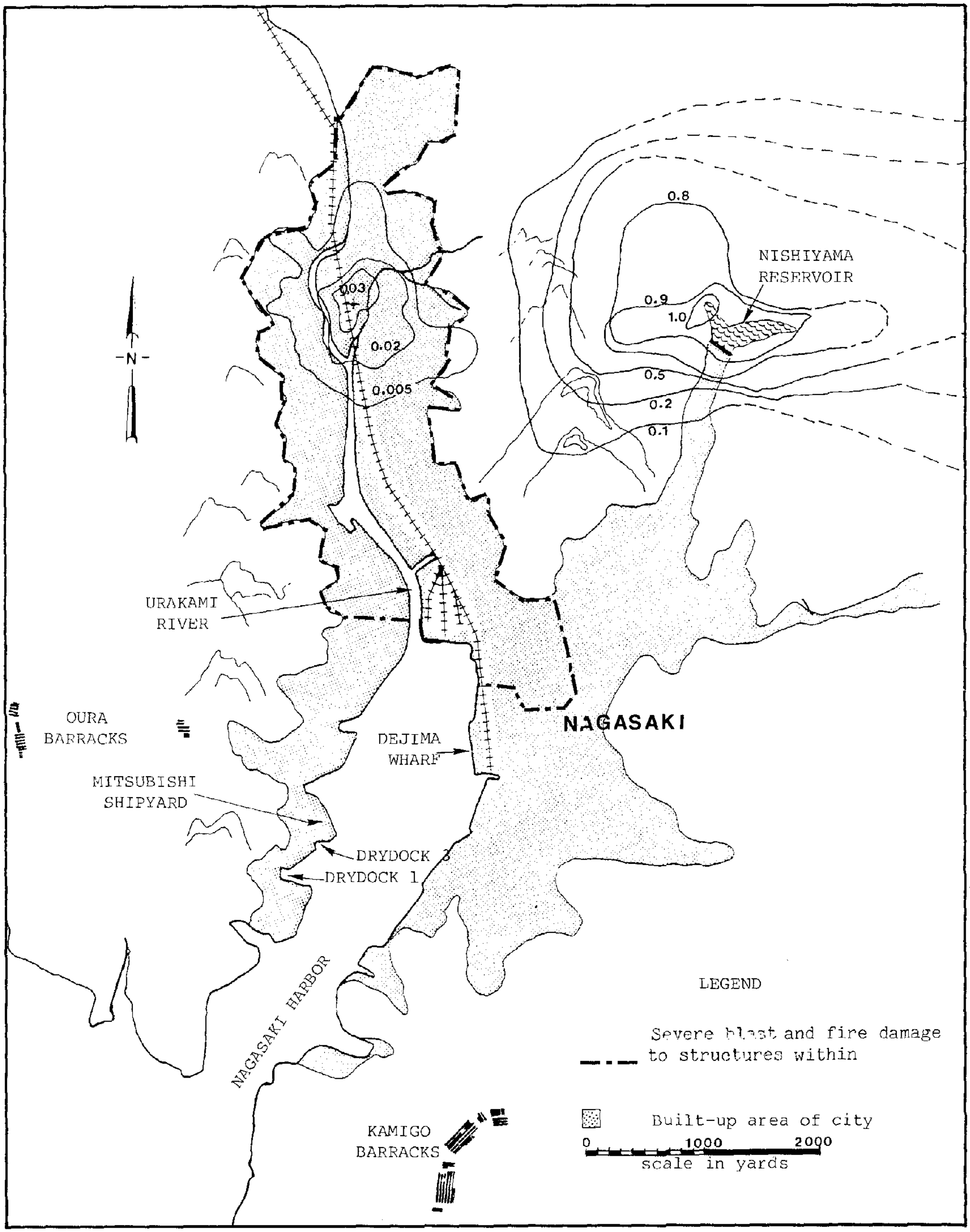

Figure 1.
RESULTS OF MANHATTAN DISTRICT SURVEY
READINGS IN MR/HR AS OF 21 SEPT-4 OCT 1945

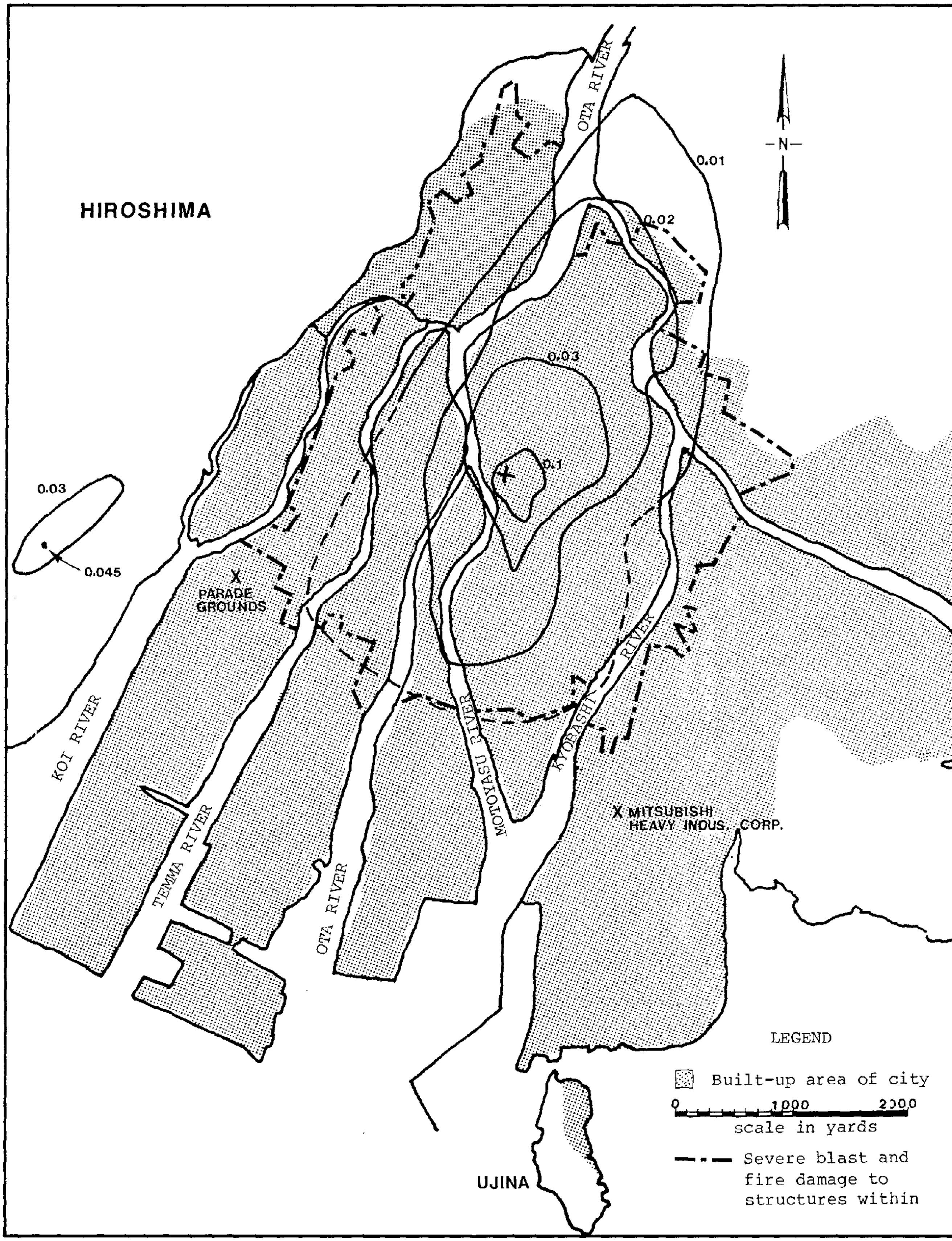

Figure 2.
RESULTS OF MANHATTAN DISTRICT SURVEY
READINGS IN MR/HR AS OF 3-7 OCT 1945

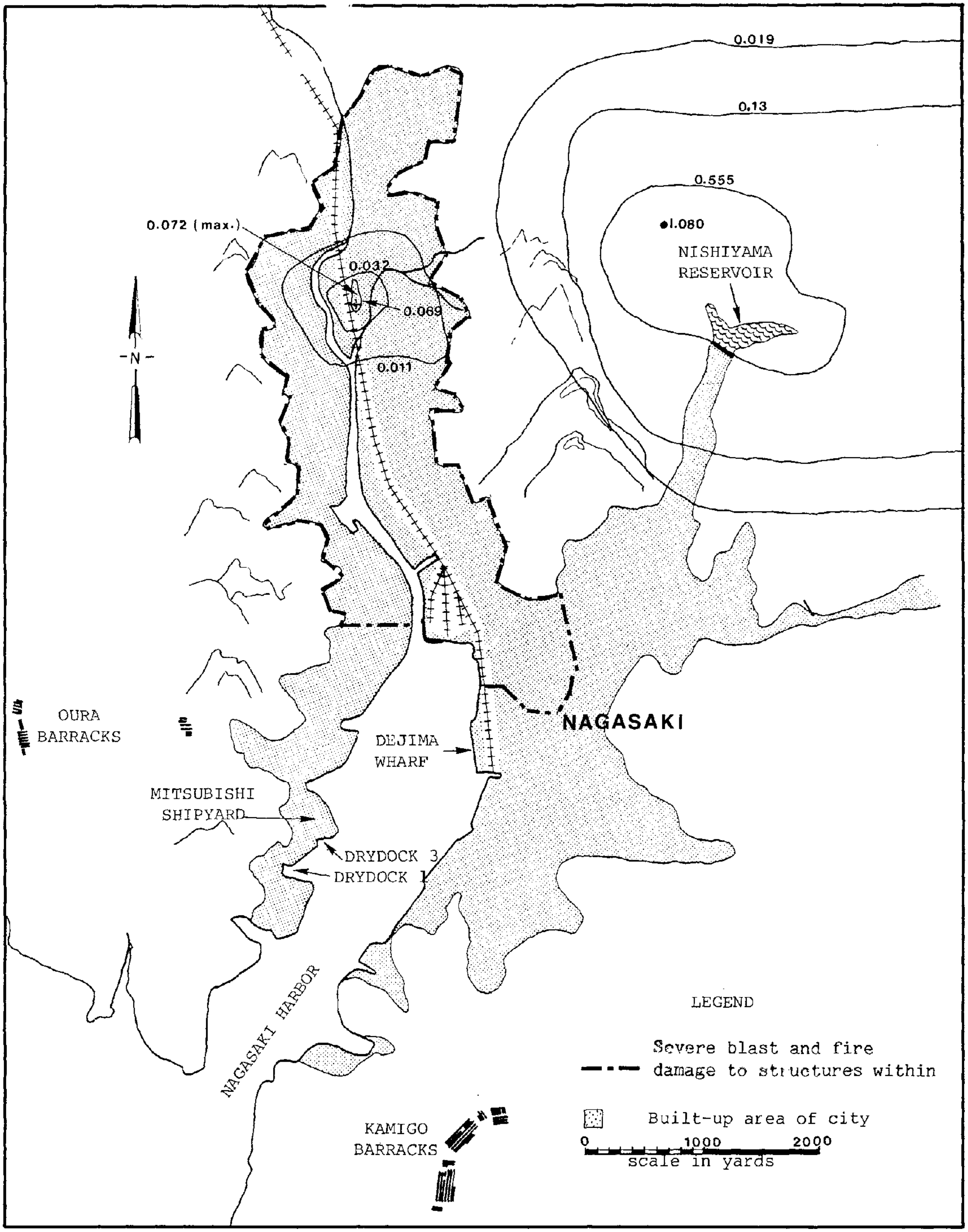

Figure 3.
RESULTS OF NAVAL MEDICAL RESEARCH INSTITUTE SURVEY
READINGS IN MR/HR AS OF 15-27 OCT 1945

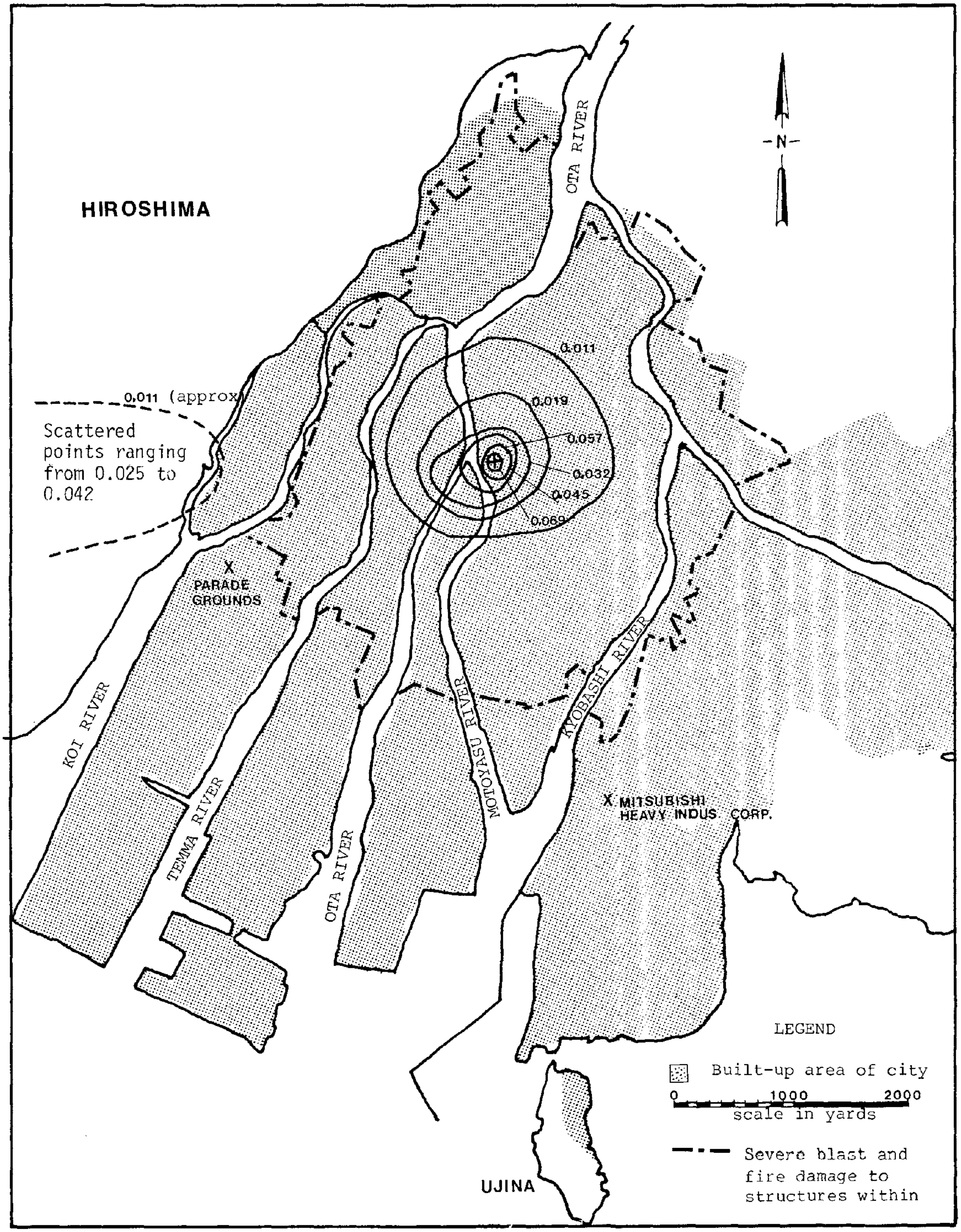

Figure 4.
RESULTS OF NAVAL MEDICAL RESEARCH INSTITUTE SURVEY
READINGS IN MR/HR AS OF 1-2 NOV 1945

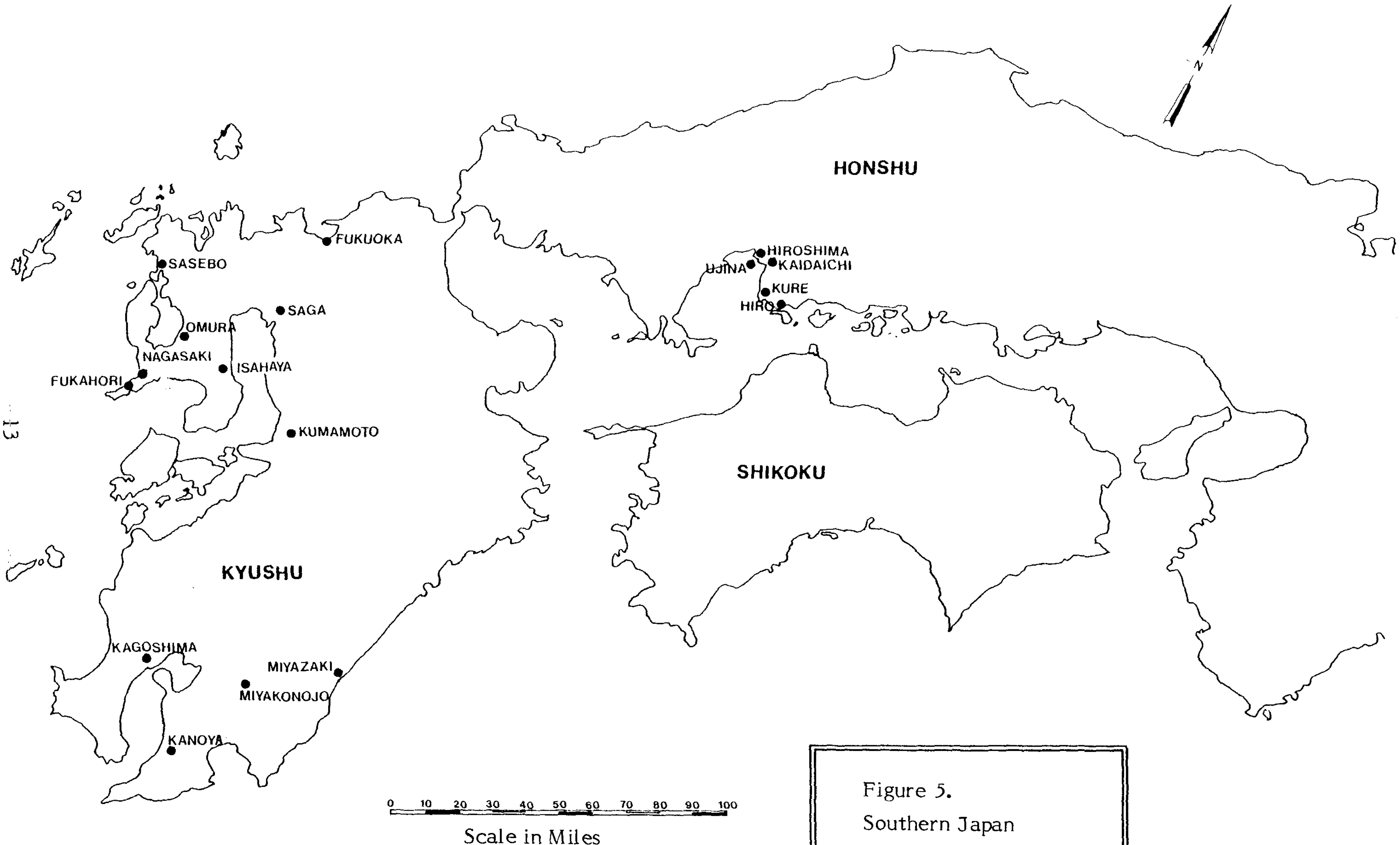

Figure 5.
Southern Japan

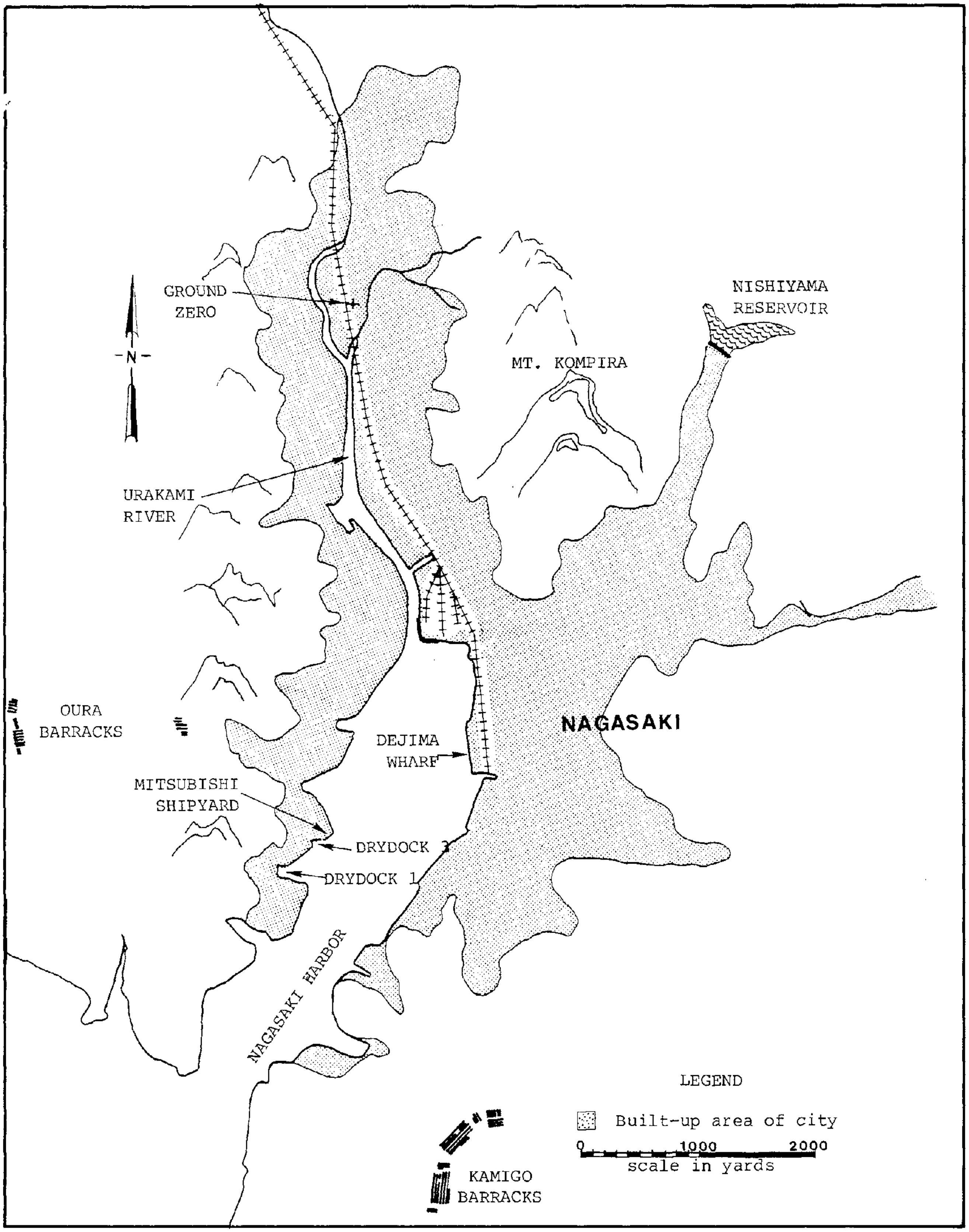

Figure 6. Nagasaki

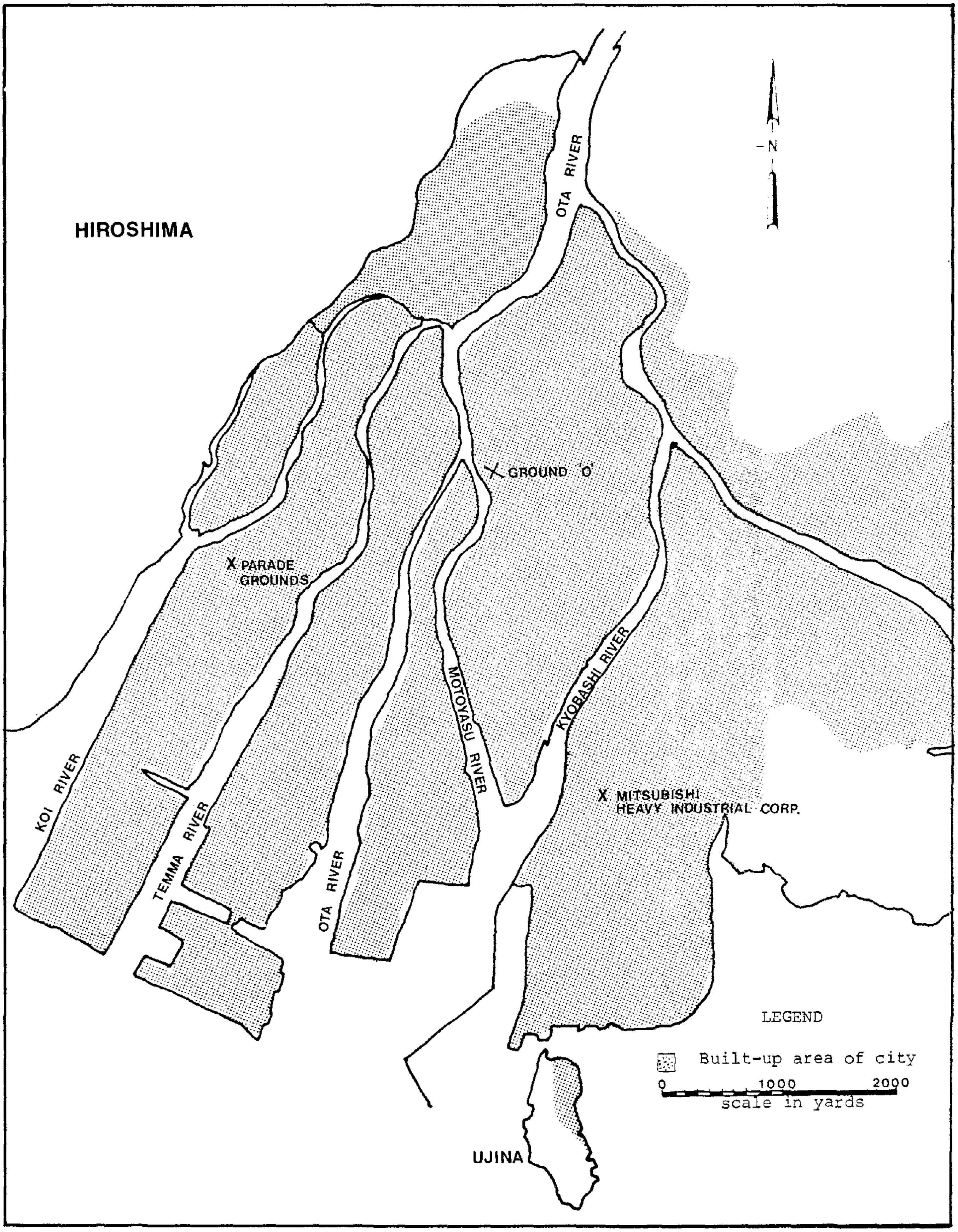

Figure 7. Hiroshima

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APPENDIX A
CALCULATION OF DOSE FROM EXTERNAL EMITTERS
(INDUCED ACTIVITY)
HIROSHIMA AND NAGASAKI

Hiroshima:

Considering the weapon height of burst and the radiation patterns determined by measurements taken on 1-2 November 1945 (see Fig. 4), it can be safely assumed that the gamma radiation detected around GZ resulted from neutron-induced activity in the soil and building materials. In an effort to estimate the external dose to Hiroshima and Nagasaki residents from this induced activity, Hashizume, et al., made calculations based on data determined experimentally[15]. Samples of soil, roof-tile, brick, asphalt, concrete, and wood were collected from Hiroshima and Nagasaki, and analyzed by neutron activation. Using this analysis, Hashizume concluded that only Na-24, Mn-56, Sc-46, Co-60, and Cs-134 need be considered in his dose estimate.

Due to the short half-lives of Na-24 (15 hours) and Mn-56 (2.57 hours), these two isotopes become insignificant at the time of occupation troop arrival at Hiroshima (H+1488) and Nagasaki (H+912). Therefore, only the longer lived isotopes of Sc-46 (84 days), Co-60 (5.2 years) and Cs-134 (2 years) need be considered in this dose estimate for the occupation units.

Using the Hiroshima soil composition data obtained from the neutron activation analysis mentioned above and estimates of the thermal neutron fluence on the ground surface at Hiroshima resulting from the bomb, Hashizume determined the specific activities (μCi/g) of the soil and various building materials (immediately after detonation) shown below:

	Sc-46	Co-60	Cs-134
Soil	5×10^{-5}	0.5×10^{-5}	2×10^{-7}
Roof-tile	17×10^{-5}	1.3×10^{-5}	5×10^{-7}
Brick	11×10^{-5}	1.1×10^{-5}	2×10^{-7}
Concrete	9×10^{-5}	0.8×10^{-5}	4×10^{-7}
Average	10.5×10^{-5}	0.92×10^{-5}	3.25×10^{-7}

From the data presented above, it is evident that Sc-46 and Co-60 were the major contributors to the gamma radiation measurements made in the ground zero area at Hiroshima on 1-2 November 1945. Since Sc-46, and Co-60 both emit 2 gamma rays per disintegration with approximately the same average energy (Co-60 slightly higher), it can be assumed that the gamma intensity measured in air from each isotope follows the same ratio as their relative specific activities in the soil and building materials. Using the average specific activities, the ratio of Sc-46 to Co-60 at time t=0 would be:

$$\frac{10.5 \times 10^{-5}}{0.92 \times 10^{-5}} = 11.41 \text{ or } 92\% \text{ Sc-46; } 8\% \text{ Co-60}$$

For each significant radionuclide, the intensity at any time can be calculated from the following expression:

$$R_t = R_o e^{-\lambda t}$$

where R_t = Intensity at time t (mR/hr)
R_o = Intensity at time t = 0 (mR/hr)
λ = decay constant = $0.693/T_{1/2}$ in hours
t = time (hours).

From Figure 4, the highest intensity contour in the neutron-activation field around GZ was 0.069 mR/hr on 1 November 1946, (D+87; H+2088). The contribution to this intensity from Sc-46 and Co-60 would be:

$$R_t = A\, R_o e^{-\lambda_1 t} + B\, R_o e^{-\lambda_2 t} = 0.069 \text{ mR/hr}$$

where λ_1 = decay constant for Sc-46 = 0.693/2016 hr = 0.0003438 hr^{-1}
λ_2 = decay constant for Co-60 = 0.693/45552 hr = 0.0000152 hr^{-1}
A = fraction* of Sc-46
B = fraction* of Co-60

Therefore:

$$R_o = \frac{R_t}{A\,e^{-\lambda_1 t} + B\,e^{-\lambda_2 t}}$$

$$R_o = \frac{0.069}{(0.92)e^{-(0.0003438)(2088)} + (0.08)e^{-(0.0000152)(2088)}}$$

$$R_o = 0.13 \text{ mR/hr}$$

Assuming that exposure to 1 roentgen results in a dose of 1 rem, the dose (D) received from each significant radionuclide from time (t_i) to time (t_f) can be calculated from the following expression:

$$D = \int_{t_i}^{t_f} R_o e^{-\lambda t} dt = \frac{R_o}{\lambda}(e^{-\lambda t_i} - e^{-\lambda t_f})$$

Therefore, at Hiroshima, the dose received by a hypothetical serviceman from the 41st Division from Sc-46 over the period 7 October 1945 (H+1488) to 1 December 1945 (H+2808) is calculated as follows:

$$D = \frac{AR_o}{\lambda_1}(e^{-\lambda_1 t_i} - e^{-\lambda_1 t_f})$$

$$= \frac{(0.92)(0.13)}{0.0003438}(e^{-(0.0003438)(1488)} - e^{-(0.0003438)(2808)})$$

$$= 76 \text{ mrem} = 0.076 \text{ rem}$$

The dose from Co-60 would be:

$$D = \frac{BR_o}{\lambda_2}(e^{-\lambda_2 t_i} - e^{\lambda_2 t_f})$$

$$= \frac{(0.08)(0.13)}{0.0000152}(e^{-(0.0000152)(1488)} - e^{-(0.0000152)(2808)})$$

$$= 13 \text{ mrem} = 0.013 \text{ rem}$$

Assuming an 8 hour per day exposure, the total dose would be:

$$D = \frac{76 + 13}{3} \simeq 30 \text{ mrem or } 0.03 \text{ rem}$$

The dose received by a hypothetical serviceman from the 24th Division from 1 December 1945 (H+2808) to 2 March 1946 (H+4992) would be:

From Sc-46:

$$D = \frac{AR_o}{\lambda_1}(e^{-\lambda_1 t_i} - e^{\lambda_1 t_f})$$

$$= \frac{(0.92)(0.13)}{0.0003438}(e^{-(0.0003438)(2808)} - e^{-(0.0003438)(4992)})$$

$$= 70 \text{ mrem}$$

From Co-60:

$$D = \frac{BR_o}{\lambda_2}(e^{-\lambda_2 t_i} - e^{-\lambda_2 t_f})$$

$$= \frac{(0.08)(0.13)}{0.0000152}(e^{-(0.0000152)(2808)} - e^{-(0.0000152)(4992)})$$

$$= 21 \text{ mrem}$$

Assuming an 8 hour per day exposure, the total dose would be:

$$D = \frac{70+21}{3} \simeq 30 \text{ mrem or } 0.03 \text{ rem}$$

<u>Nagasaki:</u>

Using a similar approach, Arakawa[14] estimated the specific activity of Sc-46 and Co-60 (at time of burst) in the Nagasaki soil to be:

Sc-46 - 16.7×10^{-5} μCi/g (average)
Co-60 - 1.1×10^{-5} μCi/g

Using the same methodology used in the Hiroshima calculation and the measurements made at GZ in Nagasaki (0.069 mR/hr on 21 October or H+1512, the midtime of the NMRI Survey):

$$R_o = \frac{R_t}{Ae^{-\lambda_1 t} + Be^{-\lambda_2 t}}$$

$$= \frac{0.069}{(0.938)e^{-(0.0003438)(1512)} + (0.062)e^{-(0.0000152)(1512)}}$$

$$= 0.11 \text{ mR/hr}$$

Therefore, at Nagasaki, the dose received from Sc-46 over the period 16 September 1945 (H+912) to 2 July, 1946 (H+7848) is calculated as follows:

$$D = \frac{AR_o}{\lambda_1}(e^{-\lambda_1 t_i} - e^{\lambda_1 t_f})$$

$$= \frac{(0.938)(0.11)}{0.0003438}(e^{-(0.0003438)(912)} - e^{-(0.0003438)(7848)})$$

$$= 199 \text{ mrem}$$

The dose from Co-60 over the same period:

$$D = \frac{BR_o}{\lambda_2}(e^{-\lambda_2 t_i} - e^{-\lambda_2 t_f})$$

$$= \frac{(0.062)(0.11)}{0.0000152}(e^{-(.0000152)(912)} - e^{-(0.0000152)(7848)})$$

$$= 44 \text{ mrem}$$

The total dose considering an 8 hour/day exposure:

$$D = \frac{199+44}{3} = 81 \text{ mrem or } 0.081 \text{ rem}$$

APPENDIX B
CALCULATION OF DOSE FROM EXTERNAL EMITTERS (FISSION PRODUCTS) HIROSHIMA AND NAGASAKI/NISHIYAMA

According to Glasstone[1], the gamma intensity from early fallout decays with time after the detonation (up to 4000 hours) according to $t^{-1.2}$, where t equals the time after detonation in hours. Between 4000 hours and 7700 hours (extent of time of interest for this study), the decay is approximately $t^{-2.2}$. Therefore, the intensity (R_t) in mR/hr at any time (t) in hours can be calculated from the following expression:

$$R_t = R_1 t^{-1.2}, \; t < 4000$$

$$R_t = R_1 (4000)^{-1.2} \left(\frac{t}{4000}\right)^{-2.2}, \; t > 4000$$

where R_1 = Reference time (H+1) intensity (mR/hr)

Since exposure to 1 roentgen of gamma radiation results in a dose of 1 rem, the dose (D) in rems resulting from an exposure from time (t_i) to a later time (t_f) can be calculated by integrating the above expression as follows:

$$D = \int_{t_i}^{t_f} R_1 t^{-1.2}\, dt = 5R_1 (t_i^{-0.2} - t_f^{-0.2}), \text{ for } t_f < 4000$$

$$D = \int_{t_i}^{4000} R_1 t^{-1.2} dt + \int_{4000}^{t_f} R_1 (4000)^{-1.2} \left(\frac{t}{4000}\right)^{-2.2} dt$$

$$= R_1 \left[5(t_i^{-.2} - 4000^{-.2}) + \frac{4000}{1.2} (4000^{-1.2} - t_f^{-1.2}) \right], \text{ for } t_f > 4000$$

In order to reflect an 8 hour per day exposure during the period, the above equation is divided by 24/8 or 3.

Hiroshima Calculation:

From Figure 4, the maximum intensity in the downwind fallout field (west of Koi River) was 0.042 mR/hr on 1 November 1945 (D+87; H+2088). Therefore:

$$R_1 = \frac{R_t}{t^{-1.2}} = \frac{0.042}{2088^{-1.2}} \simeq 405 \text{ mR/hr}$$

The dose received by a hypothetical serviceman from the 41st Division (186th Regiment) from 7 October 1945 (D+62; H+1488) to 1 December 1945 (D+117; H+2808) would be:

$$D = \frac{5(405)(1488^{-0.2} - 2808^{-0.2})}{3}$$

$$= 19 \text{ mrem or } 0.019 \text{ rem}$$

The dose received by a hypothetical serviceman from the 24th Division (34th Regiment) from 1 December 1945 (D+117; H+2808) to 2 March 1946 (D+208; H+4992) would be:

$$D = \frac{405}{3}\left[5(2808^{-.2} - 4000^{-.2}) + \frac{4000}{1.2}(4000^{-1.2} - 4992^{-1.2})\right]$$

$$\simeq 14 \text{ mrem or } 0.014 \text{ rem}$$

Nagasaki/Nishiyama Calculation:

From Figure 3, the highest intensity in the downwind fallout field around the Nishiyama Reservoir was 1.080 mR/hr on 21 October 1945 (mid-time of survey; D+73; H+1752).

$$R_1 = \frac{R_t}{t^{-1.2}} = \frac{1.080}{1752^{-1.2}} \simeq 8427 \text{ mR/hr}$$

The dose received by a hypothetical serviceman from the 2d Marine Division (RCT-2) from 24 September 1945 (D+46; H+1104) to 12 November 1945 (D+95; H+2280) would be:

$$D = \frac{5(8427)(1104^{-0.2} - 2280^{-0.2})}{3}$$

$$\simeq 470 \text{ mrem or } 0.47 \text{ rem}$$

The dose received by a hypothetical serviceman from the 2d Marine Division (Artillery Group) from 2 November 1945 (D+85; H+2040) to 26 June, 1946 (D+321; H+7704) would be:

$$D = \frac{8427}{3}\left[5(2040^{-.2} - 4000^{-.2}) + \frac{4000}{1.2}(4000^{-1.2} - 7704^{-1.2})\right]$$

$$\simeq 630 \text{ mrem or } 0.63 \text{ rem}$$

APPENDIX C
CALCULATION OF DOSE FROM INTERNAL EMITTERS
(INHALED INDUCED ACTIVITY)
HIROSHIMA AND NAGASAKI

In Appendix A it was determined that Sc-46 and Co-60 were the only isotopes of significance remaining in the GZ area at the time of occupation troop entry into Hiroshima and Nagasaki. Average specific activities (μCi/g) for soil and building materials determined by Arakawa[14] and Hashizume, et al.,[15] at time zero (immediately after detonation) are shown below:

	Sc-46	Co-60
Hiroshima	10.5×10^{-5}	0.92×10^{-5}
Nagasaki*	16.7×10^{-5}	1.1×10^{-5}

Assuming a composite (soil and building materials) density of 2.0 grams per cubic centimeter, the concentration ($\mu Ci/cm^3$) of these materials are shown below

	Sc-46	Co-60
Hiroshima	21.0×10^{-5}	1.84×10^{-5}
Nagasaki	33.4×10^{-5}	2.2×10^{-5}

Assuming that the top centimeter of soil and/or crushed building material is available for resuspension, a conservative value ($10^{-4}m^{-1}$) for a resuspension factor and a breathing rate of $1.3\ m^3/hr$, the quantity (μCi) of each radionuclide inhaled during the entire occupation period is calculated as follows:

*Soil only

$$Q = \frac{SA_o \times K \times BR}{3} \int_{t_i}^{t_f} e^{-\lambda t} dt$$

$$Q = \frac{SA_o \times K \times BR}{3\lambda} (e^{-\lambda t_i} - e^{-\lambda t_f})$$

where

Q	=	Quantity inhaled (μCi)
SA_o	=	Surface activity at time zero ($\mu Ci/m^2$)
K	=	Resuspension factor (m^{-1})
BR	=	Breathing Rate (m^3/hr)
t_i	=	Time of entry (hr)
t_f	=	Time of departure (hr)
λ	=	Decay constant
3	=	Exposure Factor (8 hour/day exposure)

Results:

For Hiroshima:

41st Division (t_i=1488; t_f=2808)	24th Division (t_i=2808; t_f=4992)
Q	Q
Sc-46 = 0.058 μ Ci	Sc-46 = 0.053 μ Ci
Co-60 = 0.010 μ Ci	Co-60 = 0.017 μ Ci

For Nagasaki: (t_i=912; t_f=7848)

Sc-46 = 0.28 μCi

Co-60 = 0.062 μCi

Using 50-year dose commitment factors from references 21 and 22, the dose to the bone and to the whole body is calculated as follows:

D = Q x DF (for organ of interest)

where D = 50-year dose commitment (rem)

Q = Quantity inhaled (μCi)

DF = Dose Factor (rem/μCi inhaled)

For Hiroshima (41st Division)

From Sc-46:

Whole body dose $= 0.058 \times 3.11 \times 10^{-2} = 1.8 \times 10^{-3}$ rem

Bone dose $= 0.058 \times 5.51 \times 10^{-2} = 3.2 \times 10^{-3}$ rem

From Co-60:

Whole body dose $= 0.010 \times 8.20 \times 10^{-2} = 0.8 \times 10^{-3}$ rem

Bone dose $= 0.010 \times 5.06 \times 10^{-2} = 0.5 \times 10^{-3}$ rem

Totals:

Whole body dose $= 2.6 \times 10^{-3}$ rem

Bone dose $= 3.7 \times 10^{-3}$ rem

For Hiroshima (24th Division)

From Sc-46:

Whole body dose $= 1.7 \times 10^{-3}$ rem

Bone dose $= 2.9 \times 10^{-3}$ rem

From Co-60:

Whole body dose $= 1.4 \times 10^{-3}$ rem

Bone dose $= 0.9 \times 10^{-3}$ rem

Totals:

Whole body dose $= 3.1 \times 10^{-3}$ rem

Bone dose $= 3.8 \times 10^{-3}$ rem

For Nagasaki

From Sc-46:

Whole body dose $= 0.9 \times 10^{-2}$ rem

Bone dose $= 1.5 \times 10^{-2}$ rem

From Co-60:

Whole body dose $= 5.1 \times 10^{-3}$ rem

Bone dose $= 3.1 \times 10^{-3}$ rem

Totals:

Whole body dose $= 1.4 \times 10^{-2}$ rem

Bone dose $= 1.8 \times 10^{-2}$ rem

APPENDIX D

CALCULATION OF DOSE FROM INTERNAL EMITTERS (INHALED FISSION PRODUCTS AND UNFISSIONED PLUTONIUM) NAGASAKI (NISHIYAMA)

FISSION PRODUCTS:

In Figure 3, the maximum radiation intensity recorded in the fallout field around the Nishiyama Reservoir was 1.080 mR/hr on 21 October, 1945, (midtime of the NMRI survey). Assuming the intensity decays according to $t^{-1.2}$, this level would be approximately 1.9 mR/hr on 24 September, 1945, the earliest date that RCT-2 could send patrols into the area.

The gamma radiation intensity (mR/hr) measured at one meter above the ground was related to the surface activity ($\mu Ci/m^2$) for the fallout from three nuclear weapons test shots at the Nevada Test Site.[25] For Shot Diablo, the ratio of the surface activity ($\mu Ci/m^2$) to the gamma intensity (mR/hr) was 179 to 1, forty-nine days after the detonation. Since the Diablo device and the Nagasaki weapon both used plutonium as the fissionable material and the time interval after the detonation is nearly the same (49 days vs. 46 days), this ratio can be used to estimate the surface activity at Nishiyama on 24 September 1945, as follows:

$$1.9 \text{ mR/hr} \times 179 (\mu Ci/m^2)/(mR/hr) \approx 340 \ \mu Ci/m^2$$

Using activity fractions of the fission product inventory at 1100 hours obtained from ORIGEN[24], the surface activity of each significant isotope at the earliest time of troop entry (24 September 1945, H+1104 hours) is calculated below:

$$SA_i = SA_t \times f_i$$

where SA_i = Surface activity of isotope i ($\mu Ci/m^2$)
SA_t = Total surface activity (340 $\mu Ci/m^2$)
f_i = Activity fraction of isotope i

ISOTOPE	f	SA_i ($\mu Ci/m^2$)
Sr-89	0.0358	12.22
Sr-90	0.0004	0.13
Y-90	0.0004	0.13
Y-91	0.0466	15.89
Zr-95	0.0840	28.66
Nb-95	0.0621	21.19
Ru-103	0.1433	48.89
Ru-106	0.0212	7.23
Rh-103m	0.1433	48.89
Rh-106	0.0212	7.23
Te-127m	0.0012	0.41
Te-127	0.0012	0.41
Te-129m	0.0078	2.66
Te-129	0.0049	1.67
I-131	0.0185	6.31
Cs-136	0.0019	0.64
Cs-137	0.0011	0.37
Ba-137m	0.0010	0.35
Ba-140	0.0653	22.29
La-140	0.0749	25.55
Ce-141	0.1219	41.59
Ce-144	0.0216	7.37
Pr-143	0.0648	22.11
Pr-144	0.0216	7.37
Nd-147	0.0197	6.72

The amount of each significant radionuclide inhaled during the occupation period is calculated using the following expression:

$$Q = \frac{SA_o \times K \times BR}{3} \int_{t_i}^{t_f} e^{-\lambda t}\, dt$$

$$Q = \frac{SA_o \times K \times BR}{3\lambda} \left(e^{-\lambda t_i} - e^{-\lambda t_f}\right)$$

when:

Q = Amount inhaled (μCi)

SA_o = Surface activity at time zero ($\mu Ci/m^2$)

K = Resuspension Factor (m^{-1})

BR = Breathing Rate (m^3/hr)

t_i = Time of entry (hr)

t_f = Time of departure (hr)

λ = Radiological Decay Constant (hr^{-1})

3 = Exposure Factor (8 hours/day exposure)

Using this equation, the amount of each isotope inhaled during the occupation period is shown below:

ISOTOPE	Q(µCi inhaled) RCT-2	Q(µCi inhaled) Artillery Group
Sr-89	4.59E-02	5.52E-02
Sr-90	6.67E-04	3.19E-03
Y-90	6.67E-04	3.19E-03
Y-91	6.16E-02	8.30E-02
Zr-95	1.14E-01	1.72E-01
Nb-95	8.43E-02	1.26E-01
Ru-103	1.67E-01	1.44E-01
Ru-106	3.52E-02	1.40E-01
Rh-103m	1.67E-01	1.44E-01
Rh-106	3.52E-02	1.40E-01
Sn-123	5.86E-04	1.44E-03
Sn-125	1.80E-04	1.05E-05
Te-127m	1.78E-03	4.02E-03
Te-127	1.79E-03	4.02E-03
Te-129m	8.58E-03	6.11E-03
Te-129	5.39E-03	3.83E-03
I-131	7.50E-03	2.65E-04
Cs-136	1.19E-02	1.84E-04
Cs-137	1.88E-03	8.98E-03
Ba-137m	1.77E-03	8.41E-03
Ba-140	3.97E-02	5.15E-03
La-140	4.56E-02	5.91E-03
Ce-141	1.31E-01	8.77E-02
Ce-144	3.54E-02	1.25E-01
Pr-143	4.14E-02	6.16E-03
Pr-144	3.54E-02	1.25E-01
Nd-147	1.06E-02	9.57E-04

The 50-year dose-equivalent commitment to the bone, red bone marrow (RBM) and the whole body resulting from the inhalation of these isotopes is calculated as follows:

$$D = Q \times DF \text{ (for organ of interest)}$$

where: D = Dose (rem)

Q = Quantity inhaled (µCi)

DF* = Dose Conversion factor (rem/µCi inhaled)

*Dose factors from References 22 and 23.

FOR RCT-2:

ISOTOPE	Q	DF (bone)	D (bone)	DF (RBM)	D (RBM)	DF (Whole Body)	D (Whole Body)
Sr-89	4.59E-02	3.38E-02	1.55E-03	1.33E-02	0.61E-03	4.76E-03	0.21E-03
Sr-90	6.67E-04	3.00	2.00E-03	1.10	0.74E-03	0.24	0.16E-03
Y-90	6.67E-04	1.95E-03	*	8.39E-04	*	9.62E-04	*
Y-91	6.16E-02	2.25E-02	1.38E-03	8.51E-03	0.52E-03	5.67E-03	0.35E-03
Zr-95	1.14E-01	9.15E-03	1.05E-03	5.46E-03	0.62E-03	5.55E-03	0.63E-03
Nb-95	8.43E-02	1.22E-03	0.11E-03	1.61E-03	0.13E-03	1.94E-03	0.17E-03
Ru-103	1.67E-01	9.12E-04	1.55E-03	1.25E-03	0.21E-03	1.98E-03	0.37E-03
Ru-106	3.52E-02	8.76E-03	0.31E-03	9.37E-03	0.33E-03	6.18E-02	0.21E-03
Rh-103m	1.67E-01	2.05E-08	*	2.28E-08	*	9.89E-07	*
Rh-106	3.52E-02	1.14E-08	*	1.43E-08	*	3.44E-07	*
Te-127m	1.78E-03	2.25E-03	*	2.52E-03	*	3.20E-03	*
Te-127	1.79E-03	8.87E-06	*	4.09E-05	*	5.13E-05	*
Te-129m	8.58E-03	3.51E-04	*	8.27E-04	*	5.54E-04	*
Te-129	5.39E-03	2.25E-06	*	6.31E-06	*	1.80E-05	*
I-131	7.50E-03	2.38E-04	*	2.02E-04	*	6.13E-04	*
Cs-136	1.19E-02	6.70E-03	0.08E-03	7.91E-03	0.10E-03	6.00E-03	0.07E-03
Cs-137	1.88E-03	4.54E-02	0.08E-03	4.91E-02	0.10E-03	3.26E-02	0.06E-03
Ba-137m	1.77E-03	1.70E-07	*	2.22E-07	*	3.21E-07	*
Ba-140	3.97E-02	5.72E-03	0.23E-03	3.61E-03	0.14E-03	2.08E-03	0.08E-03
La-140	4.56E-02	8.00E-04	0.04E-03	8.52E-04	0.04E-03	1.05E-03	0.05E-03
Ce-141	1.31E-01	1.55E-02	2.03E-03	4.07E-03	0.54E-03	3.27E-03	0.05E-03
Ce-144	3.54E-02	0.91	32.21E-03	0.35	12.46E-03	0.17	6.03E-03
Pr-143	4.14E-02	1.10E-02	0.45E-03	3.36E-03	0.14E-03	2.14E-03	0.08E-03
Pr-144	3.54E-02	1.03E-05	*	4.27E-06	*	9.75E-06	*
Nd-147	1.06E-02	9.80E-03	0.11E-03	2.75E-03	0.02E-03	2.14E-03	0.02E-03
Totals			~43E-03 or 0.043 rem		~17E-03 or 0.017 rem		~9E-03 or 0.009 rem

*Less than 1E-05

NOTE: Read 4.59E-02 as 4.59×10^{-2}

FOR THE ARTILLERY GROUP:

ISOTOPE	Q	DF (bone)	D (bone)	DF (RBM)	D (RBM)	DF (Whole Body)	D (Whole Body)
Sr-89	5.52E-02	3.38E-02	1.86E-03	1.33E-02	0.73E-03	4.76E-03	0.26E-03
Sr-90	3.19E-03	3.00	9.56E-03	1.10	3.51E-03	0.24	0.76E-03
Y-90	3.19E-03	1.95E-03	*	8.39E-04	*	9.62E-04	*
Y-91	8.30E-02	2.25E-02	1.87E-03	8.51E-03	0.70E-03	5.67E-03	0.47E-03
Zr-95	1.72E-01	9.15E-03	1.57E-03	5.46E-03	0.94E-03	5.55E-03	0.95E-03
Nb-95	1.26E-01	1.22E-03	0.16E-03	1.61E-03	0.20E-03	1.94E-03	0.25E-03
Ru-103	1.44E-01	9.12E-04	0.13E-03	1.25E-03	0.18E-03	1.98E-03	0.29E-03
Ru-106	1.40E-01	8.76E-03	1.26E-03	9.37E-03	1.35E-03	6.18E-02	0.89E-03
Rh-103m	1.44E-01	2.05E-08	*	2.28E-08	*	9.89E-07	*
Rh-106	1.40E-01	1.14E-08	*	1.43E-08	*	3.44E-07	*
Te-127m	4.02E-03	2.25E-03	*	2.52E-03	*	3.20E-03	*
Te-127	4.02E-03	8.87E-06	*	4.09E-05	*	5.13E-05	*
Te-129m	6.11E-03	3.51E-04	*	8.27E-04	*	5.54E-04	*
Te-129	3.83E-03	2.25E-06	*	6.31E-06	*	1.80E-05	*
I-131	2.65E-04	2.38E-04	*	2.02E-04	*	6.13E-04	*
Cs-136	1.84E-04	6.70E-03	*	7.91E-03	*	6.00E-03	*
Cs-137	8.98E-03	4.54E-02	0.41E-03	4.91E-02	0.44E-03	3.26E-02	0.30E-03
Ba-137m	8.41E-03	1.70E-07	*	2.22E-07	*	3.21E-07	*
Ba-140	5.15E-03	5.72E-03	0.04E-03	3.61E-03	0.02E-03	2.08E-03	0.01E-03
La-140	5.91E-03	8.00E-04	*	8.52E-04	*	1.05E-03	*
Ce-141	8.77E-02	1.55E-02	1.36E-03	2.03E-03	0.36E-03	3.27E-03	0.29E-03
Ce-144	1.25E-01	0.91	114.00E-03	0.35	43.84E-03	0.17	21.30E-03
Pr143	6.16E-03	1.10E-02	0.07E-03	3.36E-03	0.02E-03	2.14E-03	0.01E-03
Pr-144	1.25E-01	1.03E-05	*	4.27E-06	*	9.75E-06	*
Nd-147	9.57E-04	9.80E-03	*	2.75E-03	*	2.14E-03	*
Totals			~132E-03 or 0.132 rem		~52E-03 or 0.052 rem		~26E-03 or 0.026 rem

*Less than 1E-05

PLUTONIUM-239:

The weapon dropped on Nagasaki was a Pu-239 device; therefore some unfissioned plutonium would be expected in the fallout around the Nishiyama Reservoir, and above-background levels of Pu-239 have been detected in that area. Soil samples (10 cm deep) taken in relatively undisturbed areas (grasslands and graveyards) in 1969, expressed in terms of surface activity, ranged from 0.015 $\mu Ci/m^2$ to 0.038 $\mu Ci/m^2$ with an average of 0.024 $\mu Ci/m^2$[20]. These samples were taken in the general area of the maximum radiation intensity recorded in Figures 1 and 3 . Soil samples taken in nearby areas that were not contaminated by fallout from the bomb ranged from 0.001 to 0.006 $\mu Ci/m^2$ with an average of 0.004 $\mu Ci/m^2$. Using the latter results as a background level, the residual Pu-239 surface contamination from the bomb (24 years later) was about 0.02 $\mu Ci/m^2$ in the area of maximum fallout contamination. Due to the extremely long radiological half life of Pu-239 (24,000 years), radiological decay since 1945 would be insignificant; therefore any difference in the surface contamination between 1945 and 1969 would result from environmental factors. Plutonium-oxide, the most likely chemical form of the unfissioned plutonium, has been shown to be persistent in soil.

Soil samples (30 cm deep) taken in the same general area in 1970 and analyzed for Cs-137, averaged 0.8 $\mu Ci/m^2$ while similar background samples averaged 0.5 $\mu Ci/m^2$.[19] Subtracting background and back-calculating for radiological decay results in a level of 0.53 $\mu Ci/m^2$ in 1945. This agrees fairly well with the calculated value of 0.37 $\mu Ci/m^2$, especially since the exact location of these samples relative to the location of the maximum radiation intensity (1.08 mR/hr) used to calculate the surface activity is unknown. Such agreement implies that the Cs-137 contamination in undisturbed soils has not been significantly altered by environmental factors. Therefore, assuming Cs-137 and Pu-239 behave similarly, the Pu-239 soil sample data mentioned above can be used (unadjusted) to estimate the inhalation dose as follows:

$$D_i = SA \times K \times BR \times T \times DF_i$$

where D_i = 50 year dose-equivalent commitment for organ i

SA* = Surface Activity ($\mu Ci/m^2$)

K = Resuspension factor (m^{-1})

BR = Breathing rate (m^3/hr)

T = Duration of exposure (hr)

DF_i = Dose Conversion Factor (rem/ μCi inhaled) for organ i

<u>For the RCT-2:</u> (t_i = 1104 hours; t_f = 2280 hours)

Bone Dose = $0.02 \times 10^{-5} \times 1.3 \times \frac{1176}{3} \times 9.12 \times 10^2$ = 0.093 rem

RBM Dose = $0.02 \times 10^{-5} \times 1.3 \times \frac{1176}{3} \times 1.54 \times 10^2$ = 0.016 rem

Whole Body Dose = $0.02 \times 10^{-5} \times 1.3 \times \frac{1176}{3} \times 86$ = 0.008 rem

<u>For the Artillery Group:</u> (t_i = 2040 hours; t_f = 7704 hours)

Bone Dose = $0.02 \times 10^{-5} \times 1.3 \times \frac{5664}{3} \times 9.12 \times 10^2$ = 0.447 rem

RBM Dose = $0.02 \times 10^{-5} \times 1.3 \times \frac{5664}{3} \times 1.54 \times 10^2$ = 0.076 rem

Whole Body Dose = $0.02 \times 10^{-5} \times 1.3 \times \frac{5664}{3} \times 86$ = 0.042 rem

<u>TOTALS (Fission Products + Pu-239)</u>

For RCT-2:

Bone Dose = 0.043 + 0.093 = 0.136 rem

RBM Dose = 0.017 + 0.016 = 0.033 rem

Whole Body Dose = 0.009 + 0.008 = 0.017 rem

For the Artillery Group:

Bone Dose = 0.132 + 0.447 = 0.579 rem

RBM Dose = 0.052 + 0.076 = 0.128 rem

Whole Body Dose = 0.026 + 0.042 = 0.068 rem

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*Radiological decay is insignificant during occupation period.

APPENDIX E

CALCULATION OF DOSE FROM INTERNAL EMITTERS (INGESTED FISSION PRODUCTS AND UNFISSIONED PLUTONIUM IN DRINKING WATER) NAGASAKI

The maximum fallout measured in the Nagasaki area centered around the Nishiyama reservoir, one of four reservoirs that served the city. In Appendix D, the surface activity ($\mu Ci/m^2$) of each significant radionuclide at the point of maximum intensity in the fallout field was calculated for the time of occupation troop arrival. Assuming the same surface activity on the reservoir and subsequently mixed uniformly throughout (no settling or filtration of insoluble components) the concentration (C_o) of each radionuclide in the reservoir would be:

$$C_o(\mu Ci/m^3) = \frac{SA(\mu Ci/m^2) \times \text{Surface Area of Reservoir } (m^2)}{\text{Capacity of Reservoir } (m^3)}$$

According to reference 13, the surface area of the reservoir (full) is $1.39 \times 10^5 m^2$, and its effective capacity is 3.88×10^8 gal or $1.47 \times 10^6 m^3$.

In order to consider the contribution from the surface activity that may have washed into the reservoir from the adjacent watershed, the concentration is adjusted by the ratio of the size of the catchment area ($4.59 \times 10^6 m^2$)[8] to that of surface area of the reservoir and the use of runoff coefficient for similar terrain (0.35). Since the size of the catchment area is slightly larger than that defined by the 0.555 mR/hr contour in Figure 3, which is approximately half the activity level assumed above for direct deposition on the reservoir, the adjustment factor (A) is divided by 2 as follows:

$$A = \frac{\text{Catchment Area } (m^2) \times 0.35}{\text{Area of Reservoir } (m^2) \times 2}$$

$$= \frac{4.59 \times 10^6 \times 0.35}{1.39 \times 10^5 \times 2}$$

$$= 5.78$$

Assuming a water consumption rate of 2 liters ($2 \times 10^{-3} m^3$) per day, the activity of each radionuclide ingested during the occupation period is calculated from the following expression:

$$Q = DR \times A \times C_o \int_o^{t_f} e^{-\lambda t} dt$$

$$= \frac{DR \times A \times C_o}{\lambda} (1 - e^{-\lambda t_f})$$

where Q = Activity ingested (μCi)

DR = Drinking rate (m^3/day)

A = Adjustment factor

C_o = Activity concentration at time of arrival

λ = Radiological Decay Constant ($days^{-1}$)

t_f = Duration of exposure (days)

After the quantity of each radionuclide ingested has been determined, the 50-year dose commitment resulting therefrom is calculated as follows:

$$D = Q \times DF \text{ (organ of interest)}$$

where: D = 50-year dose commitment (rem)

Q = Quantity ingested (μCi)

DF = Dose Factor (rem/μCi ingested)

For the 2d Marine Division (t_f = 327 - 38 = 289 days):

ISOTOPE	SA	C_o	Q	DF (Bone)	D (Bone)	DF (RBM)	D (RBM)	DF (Whole Body)	D (Whole Body)
Sr-89	12.22	1.16	9.64E-01	1.33E-02	1.28E-02	5.23E-03	0.50E-02	1.80E-03	0.17E-02
Sr-90	0.13	0.012	4.02E-02	1.2	4.82E-02	0.43	1.73E-02	9.45E-02	0.38E-02
Y-90	0.13	0.012	4.02E-02	1.61E-06	*	6.94E-07	*	5.07E-04	*
Y-91	15.89	1.50	1.42	2.45E-05	*	1.15E-05	*	4.37E-04	0.06E-02
Zr-95	28.66	2.71	2.82	3.53E-04	0.09E-02	6.62E-04	0.19E-02	5.45E-04	0.15E-02
Nb-95	21.19	2.00	2.08	3.51E-04	0.07E-02	6.74E-04	0.14E-02	5.04E-04	0.10E-02
Ru-103	48.89	4.62	3.05	3.75E-04	0.11E-02	6.52E-04	0.20E-02	5.29E-04	0.16E-02
Ru-106	7.23	0.68	1.75	8.12E-03	1.42E-02	8.31E-03	1.45E-02	5.94E-03	1.04E-02
Rh-103m	48.89	4.62	3.04	2.30E-08	*	4.05E-08	*	8.96E-07	*
Rh-106	7.23	0.68	1.75	1.07E-08	*	1.86E-08	*	1.89E-07	*
Te-127m	0.41	0.039	5.83E-02	2.44E-03	0.01E-02	2.59E-03	0.02E-02	7.60E-04	*
Te-127	0.41	0.039	5.83E-02	1.60E-05	*	7.48E-05	*	5.34E-05	*
Te-129m	2.66	0.25	1.43E-01	1.89E-03	0.03E-02	1.34E-03	0.02E-02	1.29E-03	0.02E-02
Te-129	1.67	0.16	8.85E-02	2.15E-06	*	6.64E-06	*	1.73E-05	*
I-131	6.31	0.60	7.95E-02	3.59E-04	*	2.94E-04	*	9.08E-04	*
Cs-136	0.64	0.06	1.38E-02	1.01E-02	0.01E-02	1.20E-02	0.02E-02	9.05E-03	0.01E-02
Cs-137	0.37	0.035	1.16E-01	6.82E-02	0.79E-02	7.38E-02	0.86E-02	4.91E-02	0.57E-02
Ba-137m	0.35	0.033	1.16E-01	1.61E-07	*	2.93E-07	*	5.12E-07	*
Ba-140	22.29	2.11	4.49E-01	1.36E-03	0.06E-02	1.34E-03	0.06E-02	1.11E-03	0.05E-02
La-140	25.55	2.42	5.14E-01	3.52E-04	0.02E-02	1.02E-03	0.05E-02	1.04E-03	0.05E-02
Ce-141	41.59	3.93	2.14	4.06E-05	*	1.22E-04	0.03E-02	1.72E-04	0.04E-02
Ce-144	7.37	0.70	1.66	2.10E-04	0.03E-02	1.37E-04	0.02E-02	1.00E-03	0.16E-02
Pr-143	22.11	2.09	4.73E-01	2.31E-06	*	7.08E-07	*	2.16E-04	0.01E-02
Pr-144	7.37	0.70	1.66	5.61E-08	*	1.19E-07	*	6.84E-06	*
Nd-147	6.72	0.64	1.13E-01	5.71E-05	*	1.81E-04	*	2.69E-04	*
Pu-239	0.02	0.002	6.32E-03	5.7E-01	0.36E-02	9.55E-02	0.06E-02	4.82E-02	0.03E-02
Totals					~0.09 rem		~0.05 rem		~0.03 rem

*Less than 1E-04

Similarly for the other major units with different periods of exposure, the doses are as follows:

For the RCT-2 (t_f = 95 - 46 = 49 days):

D (Bone)	D (RBM)	D (Whole Body)
$\sim$0.02 rem	$\sim$0.01 rem	$\sim$0.01 rem

For the Artillery Group (t_f = 321 - 85 = 236 days):

D (Bone)	D (RBM)	D (Whole Body)
$\sim$0.07 rem	$\sim$0.04 rem	$\sim$0.02 rem